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The Availability of the Soil Potash

IN

Clay and Clay Loam Soils.

By FRED W. MORSE and B. E. CURRY.

NEW HAMPSHIRE COLLEGE
OF
AGRICULTURE AND MECHANIC ARTS
DURHAM, N. H.

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THE AVAILABILITY OF THE SOIL POTASH IN CLAY AND CLAY LOAM SOILS.

BY FRED W. MORSE and B. E. CURRY.

The kinds of soil on which the experiments reported in this bulletin were made are believed to represent the heavy clay or clay loam soil in different parts of the state. They are known to form a large portion of the farms in the vicinity of the experiment station, and are recognized by practical men as excellent soils for grass. They were formed from granitic rocks by the grinding action of the glaciers and by weathering, and usually lie upon a foundation of ledge on the uplands and a bed of boulder-clay in the lowlands. In some of the lowland fields the boulder-clay comes so near the surface as to form the subsoil.

Although these clay loams form a large proportion of the farming land in this vicinity, they are by no means continuous in extent, but are broken by ledge outcrops and knolls or ridges of sandy soil.

Clay soils formed from granite rocks are naturally rich in compounds of potash because they are principally made by the pulverizing and weathering of the mineral known as feldspar, which is one of the constituents of granite and richest in potash of any of the common minerals. On the other hand, sandy soils are largely formed from quartz, another mineral in the granite, which is harder than the feldspar, does not pulverize as easily and contains no potash. Therefore sandy soils differ widely in chemical composition from clay soils, and the results of these studies on heavy clay loams cannot be applied to light sandy loams.

A chemical analysis of a soil is of little use, when studied by itself, for showing the needs or capacity of that soil; but it is valuable when taken in connection with field experiments and analyses of crops. Early in the history of the experiment station several analyses were made of the heavy clay soil of the farm, which showed one per cent. of potash soluble in strong acid. This percentage would be equivalent to twenty tons of potash in the upper foot of an acre of land. This enormous

amount of potash was believed to be unavailable or else so slowly soluble as to be of little use in intensive farming.

Several successive years of observations of the hay crop, on old fields long unplowed and with no top-dressing of any sort, made it evident that the grasses were making use of the soil-potash, and the problem presented by these observations was the determination of the rate of availability of the natural potash compounds, and whether it was sufficiently rapid to produce large crops without exhausting the soluble compounds.

EXPERIMENTS OF 1905 AND 1906.

In July, 1905, samples of soil were taken from different fields on the College Farm and in the vicinity, and also samples of the hay crop growing on these soils. The crop was cut from a measured square yard, dried, weighed and prepared for analysis. The soil sample was obtained by making numerous borings with an auger within the square yard and mixing them together. The samples were usually taken to the depth of eight inches, but on the lowest fields six inches was sufficient to reach the line of subsoil.

Instead of determining the potash soluble in strong acid, as in the early work, the soils were subjected to the usual treatment of mineral analysis and the total amount of potash present determined. On arranging the results in two groups, lowland soils and upland soils, it was readily seen that there was a higher average percentage of potash in the lowland group. Since this group of soils contains more clay than the other group, it shows that the clay is richer in potash than the other soil constituents.

TABLE I.—*Potash in Soils, 1905.*

Lowland Group.		Upland Group.	
I	2.28	II	2.07
VI	2.47	III	2.32
VII	2.78	IV	2.40
VIII	3.22	V	2.07
IX	3.16	XI	2.75
X	3.56	XII	2.32
XIII	3.46	XIV	2.19
XV	3.56	XXI	2.05
XVI	2.21	XXII	2.07
XVII	3.19	XXIII	2.29
XVIII	3.96	Average	2.25
XIX	3.00		
XX	3.07		
XXIV	2.59		
XXVII	2.72		
Average	3.01		

*See footnote page 58.

No proportional relation could be seen between the yields of hay, or the percentages of potash in the crop, and the potash in the corresponding soils. But instead, it was noted that the percentages of potash in the crop were sufficiently uniform to make the total potash absorbed by the crop directly proportional to the yield of hay.

TABLE II.—*Yield of Hay per Acre and the Potash Absorbed by it 1905.**

Sample.	Yield of Hay.	Per cent. Potash.	Potash Absorbed.
I	2,875 lbs.	0.84	24.37 lbs.
VI	4,419 "	1.02	45.05 "
VII	4,802 "	1.18	56.67 "
VIII	2,809 "	1.29	36.23 "
IX	2,246 "	1.24	27.85 "
X	1,921 "	1.31	26.46 "
XIII	3,876 "	1.27	49.23 "
XV	2,703 "	1.40	37.81 "
XVI	2,587 "	1.65	42.68 "
XVII	4,056 "	0.98	39.75 "
II	2,257 "	1.46	32.95 "
III	4,461 "	1.01	45.05 "
IV	4,450 "	0.79	35.17 "
V	3,119 "	1.14	35.53 "
XI	5,717 "	1.47	84.04 "
XII	3,555 "	1.08	38.39 "

In July, 1906, samples of hay were again taken from seven of the localities tested in 1905, but the soils were not sampled. The results of the crop analyses were similar to those of the previous year, showing in general that the potash removed from the soil was proportional to the size of the crop. These results on comparatively old fields indicated that the limitations in yield were not due to lack of potash in the plant-food, which the crops could secure.

TABLE III.—*Yield of Hay per Acre and the Potash Absorbed, 1906.*

Sample.	Yield of Hay.	Per cent. Potash.	Potash Absorbed.
VII	3,322 lbs.	1.44	47.74 lbs.
IX	3,716 "	1.34	49.72 "
X	1,846 "	1.54	28.60 "
XVII	2,310 "	1.65	38.06 "
XVIII	4,065 "	1.60	64.90 "
XI	4,770 "	1.34	63.58 "
XIV	4,312 "	1.39	59.75 "

* (Correction.) In table 5, page 267, Biennial Report, 1907-1908, the figures in the column Yield of Hay are by mistake those for dry matter. The numbers should be hose of the corresponding samples in the above table.

EXPERIMENTS OF 1907 AND 1908.

In 1907 and 1908 further studies of the availability of the soil potash were made in connection with some fertilizer experiments on grass conducted by the Agronomy Department. These plot experiments afforded opportunities for securing crops from soil fertilized liberally with potash salts, and from soil with no fertilizer; also from soil to which had been added nitrogen and phosphoric acid without potash. The plats were so arranged that every fertilized one had an unmanured plat immediately beside it for comparison. The only treatment which noticeably affected the yield was the application of nitrogen in the forms of nitrate of soda and sulfate of ammonia.

At the time of cutting, samples of the crop were gathered, dried and subsequently analyzed. The yields of the different plats were obtained from the Agronomy Department.

In 1907 especial attention was paid only to the plats receiving potash alone, nitrogen alone, and the unfertilized plats adjoining them. Considerable alsike clover was mixed with the grasses this year, but was not uniform over all the plats. Separate analyses were therefore made of the clover and grasses from each plat, which required two samples of the crop from every one of the plats studied.

The application of potash had no perceptible effect on the yield of crop nor on the percentage of potash in either grasses or clover. Neither was the clover any more abundant in proportion to grasses on the potash plats when compared with the adjoining unfertilized plats.

The application of nitrogen made a marked increase in yield, and the stimulation was greater on the grasses than on the clover, causing the latter to appear less prominent on the nitrogen plats than elsewhere in the field.

Although there was a notably increased demand for potash on the nitrogen plats, due to the increased crop, there was no marked falling off in the percentage of potash in either grasses or clover, when compared with the corresponding unfertilized crop.

TABLE IV.—*Yields of Hay per Acre and Percentages of Potash, 1907.*

Plot.	Fertilizer.	Yield.	Potash in Dry Matter.	
			Grasses.	Clover.
11	None	5,202 lbs.	2.19	2.93
12	30 lbs. actual potash per A. in Muriate	4,830 "	2.18	2.89
13	30 lbs. actual potash per A. in Sulfate	1,876 "	2.11	2.55
14	None	1,902 "	2.05	2.40
25	60 lbs. nitrogen per A. in Nitrate of Soda	5,676 "	1.65	1.66
26	None	3,450 "	1.82	1.49
27	60 lbs. nitrogen per A. in Sulfate of Ammonia	5,220 "	1.79	1.79
35	None	3,850 "	1.67	2.02
36	60 lbs. actual potash per A. in Muriate	4,176 "	2.03	2.01
37	60 lbs. actual potash per A. in Sulfate	3,814 "	1.94	2.56
38	None	3,904 "	1.96	2.69

In 1908 the clover was wholly absent from the crop, which was mainly timothy. .Samples were analyzed from all other plats in addition to the potash and nitrogen plats. Results are grouped—Tables V, VI, VII—to show the effects of potash alone, nitrogen alone, phosphoric acid alone, and of the chemicals in combination. In addition to yield and percentage of potash there is given the calculated number of pounds of potash per acre removed from each plat. As in the previous year, no effect on yield was observed, except where nitrogen was applied in liberal quantities, and no fertilizer caused any definite variation in the percentage of potash found.

TABLE V.—*Effect of Potash on the Crop. Yield of Hay per Acre and Potash Absorbed by Crop, 1908.*

Plot.	Fertilizer.	Yield.	Per cent. Potash.	Potash Absorbed
11	None	2,814 lbs.	1.87	52.62
12	30 lbs. potash per A. in Muriate	2,016 "	1.93	38.91
13	30 lbs. potash per A. in Sulfate	2,452 "	1.56	38.25
14	None	2,316 "	1.33	30.80
15	30 lbs. potash per A. in Wood Ashes	2,678 "	1.47	39.36
35	None	5,866 "	1.48	86.81
36	60 lbs. potash per A. in Muriate	4,776 "	1.46	69.72
37	60 lbs. potash per A. in Sulfate	6,192 "	1.43	88.54
38	None	5,320 "	1.65	87.78
39	60 lbs. potash per A. in Wood Ashes	5,902 "	1.59	93.84

TABLE VI.—*Effect of Nitrogen and Phosphorus. Yield of Hay per Acre and Potash Absorbed by Crop, 1908.*

Plot.	Fertilizer.	Yield.	Per cent. Potash.	Potash Absorbed.
1	30 lbs. nitrogen per A. in Nitrate Soda	5,322 lbs.	1.59	84.62
2	None	3,616 "	1.61	58.21
3	30 lbs. nitrogen per A. in Sulfate Ammonia	4,292 "	1.62	69.53
5	None	3,268 "	1.85	60.45
6	30 lbs. phosphoric acid per A. in Acid Phosphate	3,232 "	1.78	57.53
8	None	2,344 "	1.67	39.14
9	30 lbs. phosphoric acid in Slag Phosphate	2,216 "	1.80	39.89
25	60 lbs. nitrogen in Nitrate Soda	7,054 "	1.25	88.17
26	None	5,674 "	1.28	72.62
27	60 lbs. nitrogen in Sulfate Ammonia	6,416 "	1.54	99.26
29	None	6,374 "	1.81	115.36
30	60 lbs. phosphoric acid in Acid Phosphate	6,492 "	1.14	74.01
32	None	5,412 "	1.73	93.62
33	60 lbs. phosphoric acid in Slag Phosphate	5,956 "	1.60	95.30

TABLE VII.—*Effect of Chemicals in Combination. Yield of Hay per Acre and Potash Absorbed by Crop, 1908.*

Plot.	Fertilizer.	Yield.	Per cent. Potash.	Potash Absorbed.
41	None	5,818 lbs.	1.79	104.67
42	30 lbs. nitrogen, 30 lbs. phosphoric acid per A	6,264 "	1.72	107.74
43	30 lbs. nitrogen, 30 lbs. potash per A.	6,900 "	2.09	146.01
44	None	6,228 "	2.06	128.29
45	30 lbs. phosphoric acid, 30 lbs. potash per A.	5,720 "	1.84	105.25
46	20 lbs. nitrogen, 20 lbs. phosphoric acid, 20 lbs. potash	5,538 "	1.81	100.24
47	None	5,174 "	1.86	96.23

These plats numbered forty-seven in all, and included sixteen that were unfertilized. Yields varied from a little less than one ton up to three and one half tons per acre.

These variations were due more to soil conditions than to fertilizers, since on the unfertilized plats the yields ranged from 2,316 pounds to 6,374 pounds. The relation between yields of hay and the removal of potash was compared on the unfertilized plats. The comparisons show clearly that as yields increased the potash was absorbed proportionally.

TABLE VIII.—*Unfertilized Plots Arranged in Order of Yield.*

Plot.	Yield.	Per cent. Potash.	Potash Absorbed.
14	2,316 lbs.	1.33	30.80 lbs.
8	2,344 "	1.67	39.14 "
11	2,814 "	1.87	52.62 "
17	3,088 "	1.51	47.55 "
20	3,124 "	1.11	34.67 "
5	3,268 "	1.85	60.45 "
2	3,616 "	1.61	58.21 "
47	5,174 "	1.86	96.23 "
38	5,320 "	1.65	87.78 "
32	5,412 "	1.73	93.62 "
26	5,674 "	1.28	72.62 "
41	5,848 "	1.79	104.67 "
35	5,866 "	1.48	86.81 "
23	6,010 "	1.62	97.36 "
44	6,228 "	2.06	128.29 "
29	6,374 "	1.81	115.36 "

A diagram, Fig. 1, plotted from the data in table VIII shows the relation even more closely. Practically by doubling the yield the amount of potash is doubled.

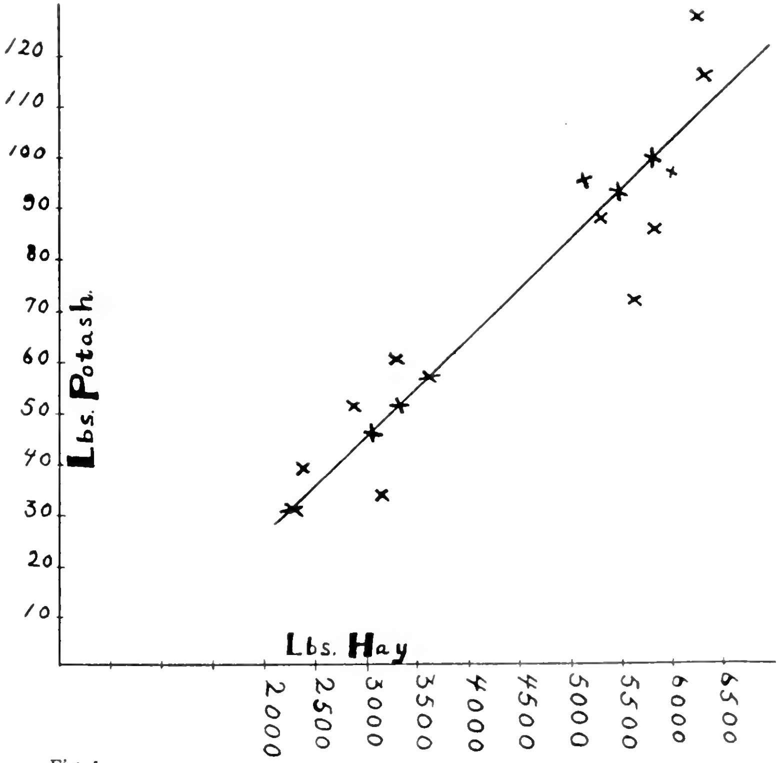

Fig. 1.

It is therefore reasonable to conclude from four successive seasons of work that on clay and clay loam soils the hay crop can obtain all the potash it needs from the potash compounds in the soil itself, and that there is sufficient potash available to supply the demands of the crop without any evidence of exhaustion.

THE WATER SOLUBLE POTASSIUM IN THE SOIL.

By another method of studying the availability of the soil-potash similar conclusions were reached regarding the continuous solubility of the potash compounds naturally present in the soil. The amount of potassium (the element from which potash is formed) which was soluble in water was determined in nearly all of the soils that have been discussed in the previous pages. The analyses were all made by the methods given in Bulletin 31, Bureau of Soils, United States Department of Agriculture, and the amounts were expressed as parts per million of the dry soil.

These determinations were all made soon after the hay crop was harvested, and therefore after the plants had used all the potash required for the season's growth.

The results for 1905 are arranged in two groups, upland and lowland, as in the case of total potash, and while both series of soils have equally low minimum results the lowland soils have a higher maximum and average than the upland soils, and the proportion of average total potash to soluble potassium is practically the same for the two groups. This is in accord with the facts that clay is richer in total potash than the other soil constituents and at the same time is formed of the smallest soil particles, which dissolve more readily than the coarser particles of silt and sand.

In 1907, 1908 and 1909 the potassium soluble in water was determined in the soils of eight of the plats in the fertilizer series, four of which were unfertilized, while the other four had been dressed with potash salts. The application of soluble potash had been thoroughly fixed in the soil, so that in spite of variations in crop yield, potash removed by the crop and potash applied as top-dressing, the amounts of potassium found to be soluble in water were practically the same for all plats in all the

seasons, and must be regarded as the lowest probable amount to be found at any time.

The average amount of soluble potassium in all the soils for the three seasons was 12.16 parts per million of dry soil, which would be equivalent to fifty-eight pounds of actual potash in a surface foot of an acre. This quantity may be assumed to be the average amount present at any time in the soil. To determine whether it is sufficient for a maximum hay crop it is necessary to compare the concentration of potash in the soil water with the necessary concentration in the current of water passing through the plant. It is definitely known that plants must get all the water that they need through the roots, and that they lose enormous quantities by transpiration through the leaves. So far as can be learned, this current of water is the means by which plants get their potash from the soil.

Numerous determinations of the moisture in the soils under discussion gave an average of eighteen per cent. water, which would be equivalent to 720,000 pounds in a surface foot of an acre, and therefore the fifty-eight pounds of potash would be dissolved in this quantity of soil water, and the concentration would be eighty parts of potash in one million parts of water.

Data for the number of pounds of water actually transpired by a crop during its growth are not abundant. King* has made numerous determinations of the total amounts transpired from the plants and evaporated from the soil in which they were growing, with results ranging from 271 pounds of water for a pound of dry matter in the corn crop to 576 pounds of water for a pound of dry matter in the clover crop. The corn, by cultivation of the soil, would have evaporation reduced to a low limit, while in clover the evaporation might be a large factor. In some experiments on the transpiration of wheat plants Livingston† and Gardner‡ have shown that there are from 40 grams to 100 grams of water used for every gram of green weight of plant. From these results it has been calculated that the transpiration of the wheat plant was approximately 300 pounds of water for one pound of dry matter in the crop. This amount

* Physics of Agriculture, p. 139.

† Bot. Gaz., 40, 178-195.

‡ Bull. 48, Bureau of Soils, U. S. Dept. Agr., p. 13.

seems reasonable for grass, since both crops require about the same soil conditions.

In 1908 four plats yielded an average crop of 6,782 pounds of hay per acre, and these crops removed an average of 104.4 pounds of potash from the soil. The actual dry matter in these crops was about 6,000 pounds, therefore there had been used approximately 1,800,000 pounds of water, and in this amount of water had been dissolved the 104.4 pounds of potash found by analysis, which is equivalent to a concentration of fifty-eight parts of potash in one million parts of water.

In one sentence, then, we may say that we have found the average concentration of the potash in the soil water to be eighty parts per million, and the approximate concentration required for the heaviest yields of hay was fifty-eight parts per million.

Therefore on our clay loams, with a total content of potash ranging from forty to sixty tons per acre in the first foot of the soil, field experiments and laboratory analyses show that the grasses have obtained and can continue to secure from the soil all the potash they need for large crops. In this discussion no mention is made of the fact that diffusion of potash occurs from the soil moisture into the plant when the concentration drops within the plant walls. This phenomenon increases the adequacy of the soil potash.

Our clay loam soil, when kept in proper condition with humus, as shown in our Bulletin 138, and supplied with nitrogen and phosphoric acid, will supply the potash without reinforcement.

HOW TO INCREASE THE AVAILABILITY OF THE SOIL POTASH.

The method which suggests itself from the results obtained by the field experiments is the frequent use of clover in a rotation. It has been noted that applications of potash had no effect in developing clover when compared with unmanured plats beside the potash plats, and further, that the clover on the unmanured soil contained practically the same amount of potash as on the potash plats. The average percentage of potash in the dry matter of clover from fifteen different plats in 1907 was

2.31, while the grasses from the same plats averaged 1.99. Hence a ton of clover would take up about six pounds more potash than mixed grasses.

Compared with timothy the difference is even greater, as that crop averaged in 1908 1.64 per cent. potash in the unmanured plats.

Clover also, as is well known, returns more nitrogen to the soil, since the results obtained in 1907 on the samples just mentioned were 2.37 per cent. of nitrogen in the clover and only 1.09 per cent. in the grasses.

It is easily seen then that by growing a crop of clover and returning it to the soil, either by plowing under or in the form of stable-manure, its decay in the soil will increase the available potash and by the increase in available nitrogen, enable new crops to use even more of the soluble native soil-potash.

EFFECT OF LIME AND PLASTER.

Lime and gypsum, or plaster, are often mentioned by agricultural writers as beneficial to soils by reason of their action on the potash minerals in the soil. Numerous experiments were tried, both in field and laboratory, to determine just what their effect might be.

In order to test this in the laboratory a number of soils were treated with lime and stirred with water. After about two months these water solutions were analyzed for potassium. It was found that the solutions from the unlimed samples carried just as much potassium as the solutions from the limed samples. Samples of soil taken from limed and unlimed portions of plats gave no different results with respect to soluble potassium. Many samples of limed soil gave slightly less soluble potassium than samples of similar unlimed soil. Since no effect was produced by liming the soils it seemed well to try the effect of lime and gypsum on the solubility of the potassium in feldspar. Feldspar, as has been stated, is the natural mineral source of potassium and is also free from clay and other disturbing factors. The high potassium content of the feldspar permits of more pronounced and more rapid results.

In this series of experiments equal quantities of feldspar were treated with lime and gypsum and stirred with water for ten

weeks. Then the solutions were filtered off and analyzed for potassium. In this case the solutions from the treated samples contained more potassium than the solutions from the untreated samples. The results appear in the table below.

TABLE. IX.—*Effect of adding Lime and Gypsum to Feldspar in Water.*

Treatment.	Total grams of potassium dissolved.	Average.	Amount dissolved by action of lime and gypsum.
Lime	.0102		
Lime	.0130	.0126	.0070
Lime	.0140		
Gypsum	.0063		
Gypsum	.0067	.0076	.0010
Gypsum	.0098		
Nothing	.0059		
Nothing	.0053	.0056	.0000
Nothing	.0059		

Column one shows the treatment; column two the amount of potassium dissolved; and column three the amount dissolved by the action of the lime or gypsum. Column three is obtained by subtracting the amount dissolved in the solutions of the untreated samples from the amount dissolved in the solutions of the treated samples.

The soils contain a greater or less quantity of feldspathic minerals, but the effect of lime on these did not produce an increase in the amount of water soluble. The inconsistency of the two series of results was more troublesome because of the fact that the lime more than doubled the solubility of the potassium in the feldspars.

In order to determine if the clay in the soil formed the disturbing factor the following experiments were made: A mixture of equal portions of feldspar and pure clay was treated with lime and stirred with water. After about ten weeks the solution from this mixture was analyzed. The potassium in solution was found to be just about the same as in the solution from the untreated feldspar. The results follow.

TABLE X.—*Comparative Effect of Lime on Feldspar, Clay, and Feldspar and Clay Mixed in Water.*

Grams Feldspar.	Grams Clay.	Grams Lime.	Soluble Potassium in Grams.
0	25	0	.0012
0	25	2	.0009
30	25	1	.0060
30	25	2	.0052
30	0	0	.0056
30	0	0	.0060
30	0	1	.0126
30	0	2	.0132

These three series of experiments show and explain a number of interesting soil conditions. When soils are limed the potassium does not become soluble and disappear because of the clay, which in turn reduces the solubility. It is because of the action of the clay that lime does not apparently increase the water soluble potassium in the soils. In certain feldspathic soils with a low percentage of clay there is little doubt but that the effect of lime would be to largely increase the amount of water soluble potassium. As yet we have not experimented with such soils. The presence of the clay unmistakably is the principal factor in conserving the soil fertility. In addition to absorbing the natural potassium it is elsewhere shown that the same influences are exerted on the artificially supplied potassium fertilizers. Further experiments show that the general effect of nitrate of soda and sodium phosphate is to increase the amount of soluble potassium in the feldspars, but this effect is not evident when these are applied to soils. The general effect of clay seems to be a tendency to lower the solubility of the soil minerals. This effect is more easily observed when clay is mixed with lime and water. Under such conditions the lime in solution may be only about one thirteenth as much as when lime is dissolved in pure water in the absence of clay.

LIME AFFECTS THE MOVEMENT OF WATER.

As has been mentioned elsewhere, a continuous movement of soil water is in progress. After rains the excess of water percolates downward through the spaces between the soil grains. At other times the movement of the water is upward toward the

surface. In some soils these water movements take place very slowly. After rains the evaporation carries away more water than is carried away by percolation. This is particularly true of many boulder-clay soils. In other more sandy soils the water percolates very rapidly and almost never stands on the surface for more than a few minutes after the rain ceases. The difference in the soil structure affects the rate of the water movements. The sandy soils are usually coarse-grained, with large spaces between the soil grains or particles. These spaces form readily accessible waterways and permit of good drainage. On the other hand, the clay soils are much different. The soil particles are fine and the spaces between the particles are very small. The water in these soils carries very fine particles of soil in suspension. As the water goes through the already minute waterways portions of these small particles are left behind and in time clog up the small spaces still more. Finally the soil becomes almost impervious to water and in such places "hard pan" is formed. Obviously such soils would be benefited by anything that would cause the soil to form larger grains and thus help to establish better waterways. Such things as lime, gypsum, muriate of potash, etc., have much to do with this flocculation. A clay soil that has been limed well will not dry in hard lumps as does the same soil unlimed. On drying the limed portion will be granular and porous, while the other will form a compact mass. The water movements may take place much more readily in the treated soil.

The water movement in a clay soil may be easily studied in the laboratory. A column of soil is prepared as in the absorption experiment, which is discussed below. When pure water is allowed to percolate through this column, it moves more and more slowly until finally almost no movement occurs unless effected under pressure. The waterways become almost completely closed. On the other hand, if solutions of lime or potassium salts be substituted for the pure water, the rate of percolation begins to increase until finally a fair rate is again established. These solutions cause the soil particles to become more granular and form larger spaces for waterways. This is undoubtedly the cause of a large part of the good results sometimes obtained when lime is applied to clay soils. In this same

connection the freezing and thawing processes which take place during the winter play a very important rôle. There is no evidence that these processes increase in any way the solubility of the plant food. On the other hand the soils are usually more porous in the spring after the frost is gone. During the freezing and thawing, ice is formed, melted, and reformed between the soil particles. This pushes the particles farther and farther apart and permits of both better drainage and aëration. On this account the effect of freezing and thawing is much the same as the effect of lime and other chemicals.

WHAT BECOMES OF THE POTASH ADDED IN THE FERTILIZERS?

What interests us in a practical way is the natural disposition of fertilizer after it is applied to the soil. Do the rains wash it into the brooks and away, does it leach deep into the soil and change into a different and insoluble condition, or do the plant roots gather it up to use for food?

We know with certainty that the rains, except in special cases, carry very small amounts of fertilizer into the brooks. Very little waste comes about in that direction. In some localities, the heavy rains carry away the entire top portions of the soil and, of course, such losses are great, but not at all common. Excepting in sandy soils, the fertilizer does not readily leach downward to any great extent. In most crops the root system is very extensive and the entire few surface inches of the soil are filled with a mass and network of roots. These may take up large quantities of the added fertilizer and remove it in this way.

In this connection a very important process is going on continuously in the soil. The soluble matter is changed into an insoluble condition. More dissolves and is again made insoluble. This changing from a soluble to an insoluble form is known as absorption.

The absorption of the soil is shown in a large and practical way by an examination of the brook and spring waters. Often less than one part in 5,000 parts of these waters is mineral matter, or stated otherwise, the brook and spring waters carry less

than one pound of mineral matter per two and a half tons of water. This means a very dilute solution. This same phenomenon is easily reproduced in the laboratory and shows how the soil removes soluble matter from solutions; or, in other words, keeps the minerals in solution down to the lowest possible amount. If a solution containing a known amount of potassium chloride is allowed to slowly percolate through a column of soil, a large part of the potassium is removed. This is shown by determining the amount of potassium passed into the soil and also the amount that appears in the percolate. The difference represents the amount taken up by the soil. If the solution is percolated slowly, nearly all of the potassium is removed from the first portions. Experiments of this sort show that the strong clay soils may remove large quantities of soluble potassium. One hundred pounds of soil is capable of taking up more than one pound of potassium. This is rather significant, if we stop to consider just what it means. An application of 1,000 pounds of fertilizer per acre is a generous amount. About 20% of this, or 200 pounds, represents the amount of plant food. The soil 8 inches deep over an acre weighs about 2,000,000 pounds. Then we have mixed one pound of plant food with 10,000 pounds of soil. This is just about one hundredth of the amount that many soils can readily absorb or render insoluble. It is thus evident that the plant food added as fertilizer is not likely to be easily washed from the soil. The experiments in the laboratory show that the soil prevents the soluble plant food from leaching deeply into the soil. Very short columns of soil will remove practically all the potassium from the first portions of the percolate. These solutions are made up to contain only a few hundred parts of potassium per million parts of water. When the potassium is once removed from solution it goes into solution again only very slowly, and it is not practical to try to remove it all by washing with pure water. A clay soil will absorb much more potassium than a sandy soil and thus, as we would expect, the potassium would leach into the sub-soil more readily in the absence of clay. This is one reason why barnyard manure disappears more rapidly when spread on sandy soils.

EXPERIMENTS SHOWING ABSORPTION.

Three soils were selected to show the absorbent effect on potassium salts. One of the soils was a boulder clay, another a light sandy loam and the third a sandy clay. These were chosen to represent soils with three different amounts of clay. Equal amounts of these soils were carefully mixed with equal amounts of potassium chloride and set away in sealed jars for three months. Then the contents of each jar were shaken with water and the amount of dissolved potassium determined. The following table shows the amount of soil taken, the amount of potassium added, the amount of potassium absorbed and the amount recovered in the solution.

TABLE XI.—*Showing the Absorptive Powers of Clay, Sandy Clay, and Sandy Loam Soils in Relation to Potash.*

Grams of Potassium Chloride Added.		Grams Potassium Chloride Recovered.	Grams Potassium Chloride Made Insoluble.
Clay Soil	1.50	.52	.980
	1.00	.435	.565
	.50	.125	.375
	.25	.075	.175
Sandy Clay Soil	1.50	.885	.615
	1.00	.555	.440
	.50	.275	.225
	.25	.130	.120
Sandy Loam	1.50	.990	.510
	1.00	.621	.379
	.50	.300	.200
	.25	.135	.115

These results show how much more readily the clay soil changes the potassium to an insoluble condition. Had the moisture content of the soils been higher, more potassium would have been changed. After potassium salts are applied to soils, it is difficult to recover any appreciable part of it afterwards. These experiments show why this is true. The clay soil, as seen in these experiments, removed about two thirds of the amount added, while the soil containing the least amount of clay acted on only a little more than half as much.

The conditions in these experiments are much less favorable for changing the potassium into an insoluble form than is found under normal field conditions, where there are large fluctuations

in the moisture content. After a lapse of more time, further analyses showed that the potassium was still undergoing changes. These experiments show why plant food washes out of sandy soils more readily than from the clay soils. What is true of potassium in this respect is also true of phosphoric acid.

As absorption experiments show, not all of the potassium is rendered insoluble. A portion is left in a soluble condition. This may in part be leached out and lost, but there is a conservative force which enters here and prevents a large part of this apparent loss. These experiments show that for a time after the application of potassium salts the amount of soluble potassium may be greater than that under natural conditions. However, the tendency is toward a lessened amount of soluble potassium until a normal amount is finally reached. The chief and most beneficial effects from fertilizers must undoubtedly be obtained while this readjustment is taking place. During the rainy season the tendency of the soil water and soluble plant food is downward. During fair weather and a large part of the growing season, the movement of the soil water is upward. A great deal of the soil water evaporates from the surface and leaves the soluble mineral matter behind, and very near the surface. These processes go on continually in one direction or the other and the actual soil fertility in this respect is kept very nearly constant. What fertility is carried down in the rainy season is carried up again in fair weather by the soil moisture.

The soils are composed largely of mineral and to a less extent of organic matter. The organic matter behaves very much as does the clay or mineral portions toward the potassium salts. When the organic matter is carefully extracted from soils and properly washed, it has absorptive properties. Small amounts of potassium are made insoluble when in contact with the extracted matter. This absorptive property is more in evidence when dried muck is treated with solutions of potassium salts. Some mucks which were 90% organic matter have been found to remove as much as one per cent. of potassium from solution. The organic matter in its natural condition has a greater absorptive capacity than it has after being extracted or separated from the soil. From the nature of the organic matter, it is a very important source of plant food. When it decays or is oxidized

large quantities of mineral plant food, as well as the nitrogen, are made available. When potassium salts are once absorbed by the organic matter, they are washed out with water only very slowly. After rains the evaporation carries away more water clay is the same. Because of the oxidation which breaks up the organic matter, the plant food there ought to be more available than that which is absorbed in the clay.

SOME EFFECTS OF AIR-SLAKED OR CARBONATE OF LIME.

We have already seen how an ordinary soil acts on chloride of potassium to make the potassium insoluble. At the same time other interesting changes take place. While the potassium goes out of solution, certain other bases, including lime, iron and aluminum, go into solution. In other words, the potassium exchanges places with these bases and becomes insoluble, while they become soluble. Laboratory experiments show that the nature of the soil determines what new bases become soluble under such conditions. If a soil poor in lime is treated with potassium chloride, relatively large amounts of iron and aluminum become soluble. On the other hand, if the soil is rich in lime, almost no iron or aluminum dissolves, but a large quantity of lime goes into solution. This difference is of much practical importance. If a soil forms soluble iron and aluminum when treated with chloride of potassium or sulfate of ammonia, it is likely to produce harmful instead of helpful results. Aside from the deleterious effects of these bases, hydrolysis causes the formation of free acids, which are also harmful. The application of lime to such soils prevents the solubility of the iron and aluminum, and also the formation of acid conditions.

It has been noted that when sulfate of ammonia was applied to certain soils[1] acid conditions were established which caused a very poor crop yield. This condition was found to be changed by application of lime along with the ammonium sulfate. While no soluble iron was detected in these soils, it is quite possible that a part of the trouble was caused in this way. The lime would remove any soluble iron and aluminum and at the same time lime and its salts exert a very marked influence upon plant growth and particularly upon the root systems.

[1]Wheeler Rhode Island Station Report, p. 212, 1893.

In order to show how lime prevents the solution of iron and aluminum, the following experiment was tried in the laboratory: A clay soil was shaken with a solution of potassium chloride and filtered. The filtrate contained large quantities of iron and aluminum, but very little lime. To a second portion of the clay a quantity of carbonate of lime was added, and the mixture shaken with a new solution of potassium chloride and filtered. This solution contained no iron or aluminum, but fairly large amounts of lime. The carbonate of lime had prevented the solution of iron and aluminum and in the process a considerable quantity dissolved. This going into solution was a part of the process because the carbonate of lime does not go into solution in the absence of the chloride of potassium. The action of lime and its effect on root growth will be discussed more at length in a subsequent paper.

SUMMARY.

Summing up these observations we have found that:

First—The clay and clay loam soils carry large quantities of potash.

Second—The potash in these soils is soluble enough to supply potash for heavy crops of grass without artificial reinforcement.

Third—Additional potash when supplied in commercial fertilizers does not affect the yield or the composition of the grasses.

Fourth—The amount of potash required for a grass crop is proportional to the yield.

Fifth—A comparison made between the amount of water soluble potash in these soils, the amount of potash in the crop, and the amount of soil water required to produce the crop, shows that the addition of potash fertilizers is not necessary. This relation stands for these soils when large yields are produced by the addition of other fertilizer.

Sixth—It is shown that when lime reacts with feldspathic minerals the potash dissolves. Also when clay is present, as in these soils, no increased amount of soluble potash is produced. This is because of the action of the clay on the solubility of potash.

Seventh—A large part of the potash in fertilizers is changed to an insoluble condition soon after it is applied to the soils.

Eighth—When the potash is rendered insoluble other bases go into solution. Lime has decided effects on these by-products.

* Bulletin 141 was incorrectly paged 245-280, and should have been paged 1-36. The present bulletin is therefore paged 37-58.

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